R&D on Future Accelerators

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URA Visiting Committee
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Outline

- Goals and Strategy
- Accelerator R&D Program
  - Linear Collider
  - Proton Driver
  - Superconducting RF
  - Muon Facilities
  - Superconducting Magnets
- Resources/Budgets

Note: This presentation does not cover the significant accelerator R&D program operating in support of Collider Run II, nor the LHC accelerator research program.

Goals

- To develop options for future Fermilab initiatives in accelerator-based HEP.
  - Develop new accelerator technologies to support Fermilab's long-term accelerator-based HEP mission.
  - Establish capabilities that will allow Fermilab participation as a leading partner in, and a credible host for, the construction and operations of the next forefront facility for HEP
  - Maintain strong research programs at Fermilab in the enabling technologies of High Energy Physics: superconducting magnets and rf

- To advance knowledge in fundamental accelerator R&D and to partner with universities in the training of new students.

Strategy

- Considerations
  - There exists a world consensus advocating construction of an electron-positron linear collider as the next forefront HEP facility.
    - However, a linear collider is not assured at this time, either in the U.S. or at Fermilab.
    - The optimistic timeframe for start of construction is now identified as 2009.
  - Interim/alternative possibilities are under consideration in a number of planning exercises.
  - Existing Proton Source has finite lifetime--current goal is efficient operations through 2010.
  - Available resources are insufficient relative to needs
    - Funding effectively flat
    - People diverted into Run II

Strategy

- Level of effort is being maintained on R&D aimed at supporting U.S. linear collider design efforts and establishing Fermilab as a credible host/construction partner.
- Effort in other areas is at the minimum level required to maintain viability.
  - Note: In some cases "viability" means documentation of current status and suspending activity pending movement on other fronts.
- Once a direction has been established through the variety of planning exercises in place we anticipate consolidating resources.
  - Fermilab is likely to play the leading role in the U.S. contribution to any forefront international project no matter when/where it is built.
- We continue to try to nurture accelerator R&D initiatives in the local universities via this process.

Accelerator R&D Program
Elements of the Program

- Linear Collider
  - X-band (NLC collaboration)
  - Superconducting (TESLA collaboration)
- Proton Driver
- Superconducting RF
  - Fermilab NICADD Photoinjector Laboratory (FNPL)
  - CKM
  - High Brightness Photoinjector (HBPI)
- Muon Facilities
- Superconducting Magnets

Linear Collider

The US community has now endorsed a linear electron-positron collider, constructed as an international endeavor and based on the optimum technology, as the next forefront facility in support of High Energy Physics. This sentiment has also been expressed by the our European and Asian colleagues.

Goals

- Complete NLC R&D work leading up to a technology demonstration (late 2003/early 2004).
- Contribute to the technology decision (mid-2004)
- Understand the ramifications of building a linear collider at Fermilab

Linear Collider
NLC

- The scope of work that Fermilab is undertaking has been severely constrained by the budgets of FY02-FY03, and more recently by the redirection of resources onto Collider Run II.
  - Budget stagnant since FY01 ($2.5M) at level less than half of that anticipated when we started this program.
  - Strategy is to focus effort in areas where we have some momentum and available people.
    - Emphasis on cavity development and civil/siting studies
    - RF development activities, including creation of an x-band power facility on-site, have been suspended.
    - The very successful permanent magnet development activity has been dramatically reduced following transfer of lead scientist to Tevatron Dept.
    - Accelerator Physics group has been redirected onto Run II.

Linear Collider
NLC

- Primary responsibilities within the NLC Collaboration now include:
  - NLC Structures
    - Structures fabrication for 8-pack test
    - Development of a fabrication/industrialization methodology
    - Development of girder designs
  - Site Studies
    - Preliminary studies of potential northern Illinois sites
    - Providing overall coordination (Vic Kuchler) of all NLC civil activities including Illinois and California

Linear Collider

NLC Structures

- We have produced three 20 cm long traveling wave structures: FXA-001, FXA-002, and FXA-003.
  - These were used to learn how to fabricate and assemble structures, and to work out most of the bugs in the RF factory.

- We have produced two 60 cm long high gradient test structures: FXB-002 and FXB-003.
  - FXB-002 was the first Fermilab X-Band structure to undergo high power RF testing (in the NLCTA at SLAC). It performed better than some, not as good as others. It was made without hydrogen cleaning.
  - FXB-003 was received at SLAC on 3/6. It underwent hydrogen cleaning, as will FXB-002 upon its return from SLAC.
  - FXB-004, 005, 006 should be at SLAC in June.

Linear Collider
NLC Structures

FXB-002 at SLAC prior to high power testing, November 2002.
N. Solyak, C. Boffo, D. Finley, G. Romanov, T. Arkan and H. Carter.

Linear Collider

NLC Structures

FXB-002 Bead pull tuning

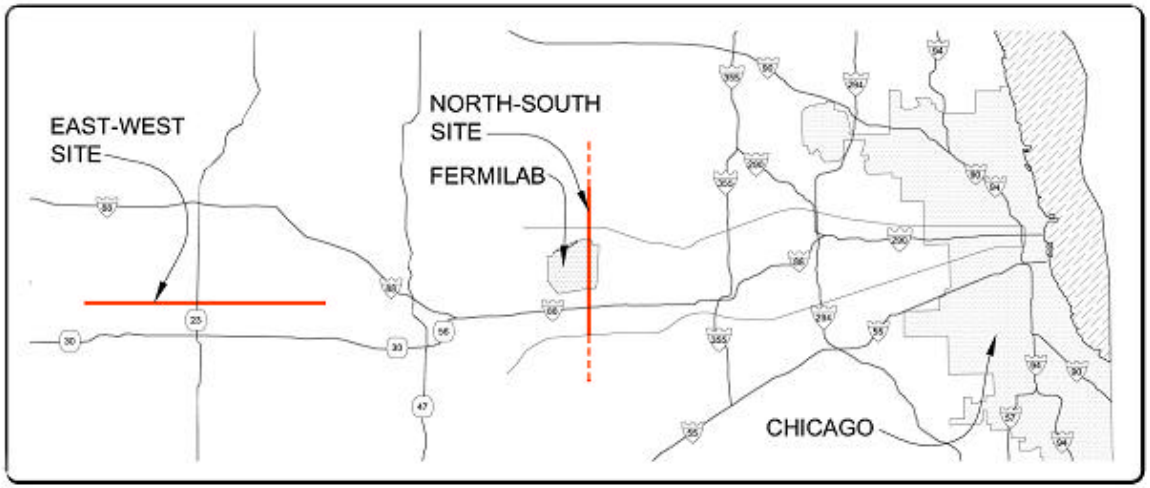
- We are continuing to improve our fabrication methods and processes, but are having problems with the large furnace.
- We are working to broaden our base of vendors capable of producing high precision machined parts for structures (2 for disks and 3 for couplers).
- We have improved our in-house RF design capabilities through the purchase of more powerful software and hardware, and through collaboration with our SLAC and KEK colleagues. We now design our own couplers.

Linear Collider
NLC Support Girders

- We are just beginning to conduct girder tests, initially using a SLAC supplied test assembly.

SLAC Thermal Stability Test Girder in the MP8 Enclosure at Fermilab

Linear Collider
Site Studies



- Preliminary analyses of N-S and E-W sites completed over FY2001-02.
- FY2003 siting activities are being conducted under the auspices of the USLCSG sponsored warm/cold evaluation:
  - SC linac in a deep site near DeKalb, IL
  - Warm linac in a bored tunnel SE of Livermore, CA (Copper Mtn.)
  - Analysis of incremental changes/costs for the alternatives.

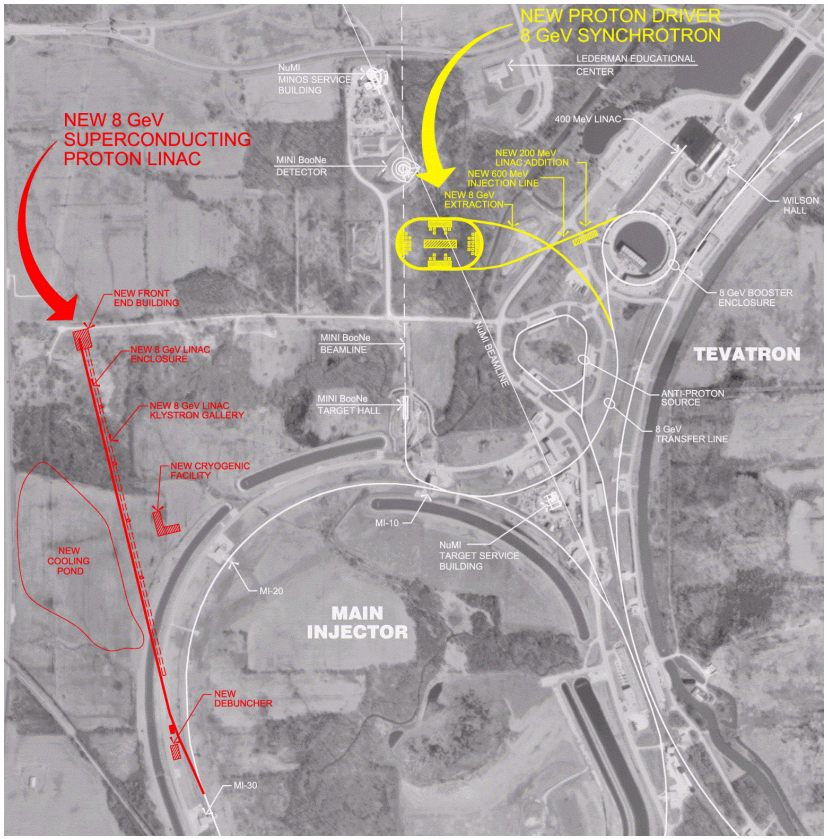
Linear Collider
Goals through FY05

- Deliver 5.4 meters of X-Band structures for the 8-Pack Test. (CY2003)
  - Mix of FXB test structures, and 75 cm "full feature" structures (FXC's) with damping manifolds.
- Develop girders for the Main Linac structures.
  - We are beginning to develop a design design with a kinematic support system and multi-axis positioning capability.
- Significantly ramp up the Linear Collider R&D effort in FY05.
  - Main Linac Beam Line Components
    - Structure industrialization
    - Linac girders
  - Siting and civil construction
- Significant contribution to the "warm and cold" evaluation of linear colliders commissioned by the USLCSG.

Linear Collider
TESLA

- Fermilab remains a member of the TESLA collaboration (and the only institution affiliated with both NLC and TESLA collaborations), but after several years of active discouragement from the DoE contributions are now minimal.
  - Modest continuing consultation support for TTF
  - Engineering/cost study of the TESLA proposal completed in July 2002. (TM-2179)
  - Global Accelerator Network (GAN) activities at FNPL
- The most significant involvement of Fermilab relative to a superconducting linear collider is now occurring via the USLCSG sponsored evaluation.
  - Fermilab is providing leadership/support in the accelerator technology, site development and cost estimating task forces. All of these draw on our considerable past experience in these areas, including the TESLA engineering/cost study.

Proton Driver



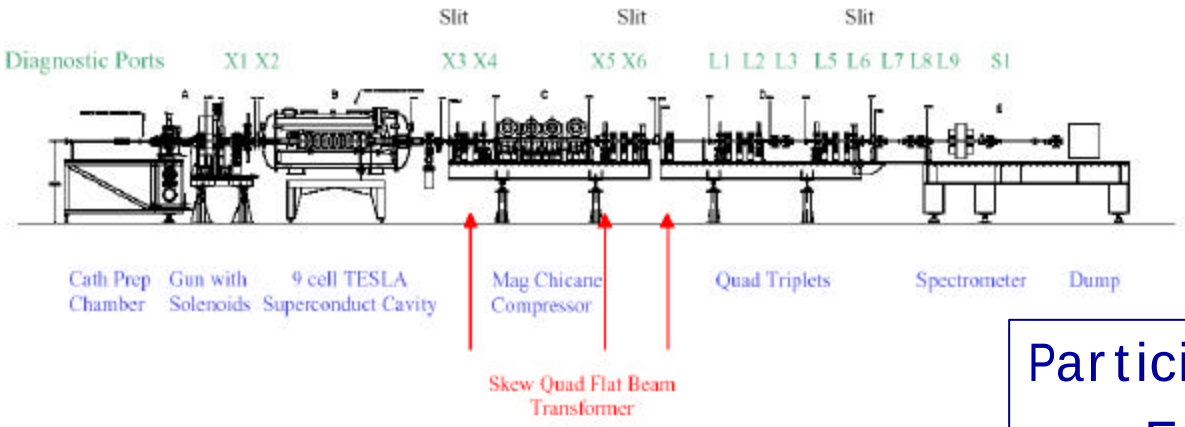
- Two concepts identified for a new 8 GeV proton facility at Fermilab
  - 0.5 (synchrotron) to 2.0 (linac) MW beam power at 8 GeV.
  - Both enable up to 2 MW at 120 GeV from MI (with upgrades)
  - $0.25-$0.5M price tag
- Study completed in May 2002 (no work since)
- Incorporated into DOE/Science Facilities list
- Plan to reinitiate R&D in FY05

Proton Driver
Parameter Table

	Present Booster	Proton Driver / Synchrotron	Proton Driver / SC Linac	
Output Energy	8.0	8.0	8.0	GeV
Protons per pulse	5×10^{12}	2.5×10^{13}	1.5×10^{14}	
Repetition Rate	15	15	10	Hz
Pulse Length	1.6	1.6	1000	μsec
Transverse emittance	15π	40π	10π	mm-mr
Average beam current	12*	60	240	μA
Average beam power	0.1	0.5	2.0	MW

(*) Although originally designed for 15 Hz operations, the present Booster has never delivered beam at 15 Hz continuously. It is designed to operate in the near future at 7.5 Hz for MiniBooNE operations.

Superconducting RF
Fermilab NICADD Photoinjector Laboratory (FNPL)



15 MeV, laser-driven electron beam facility.

Copy of the TTF injector

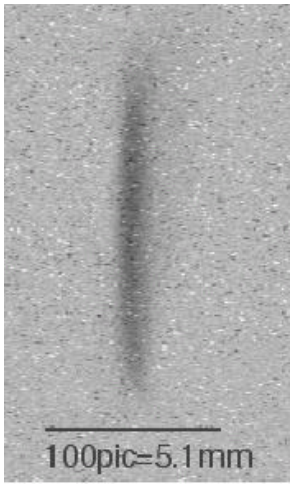
- 8 nC/pulse
- 30 psec (rms) bunch length

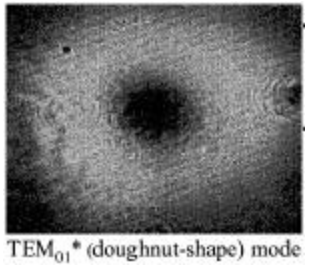
Participating institutions:

- Fermilab
- NIU
- UCLA
- Chicago
- Rochester
- DESY
- LBNL

FNPL
Current Program

- Flat Beam $\varepsilon_x \ll \varepsilon_y$
- Plasma wakefield acceleration (PWFA)
- RF Gun Quantum efficiency measurements & breakdown studies
- 9 cell Superconducting cavity transfer matrix
- Gun & solenoid beam based alignment
- Injector emittance and beam size comparison with simulation
- Plasma density transition leading to electron trapping
- Laser acceleration with donut mode laser and open iris structure
- Interferometer bunch length measurement, compression & CSR studies

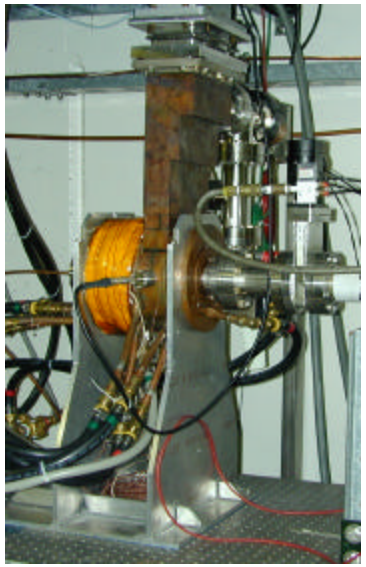




Laser acc

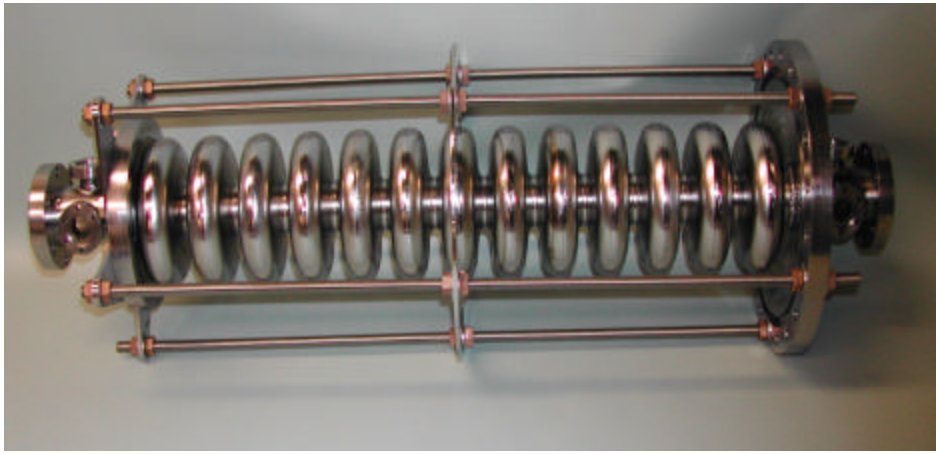
FNPL
Future Directions

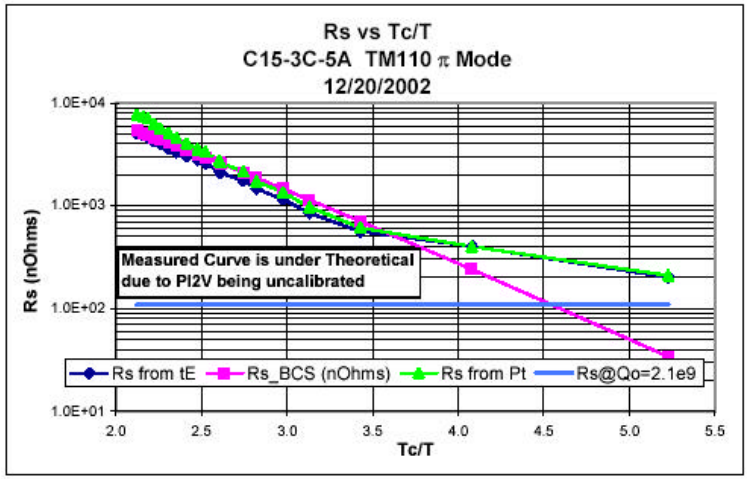
- Near term
  - separate chicane and flat beam transformer
  - install laser acc and plasma density experiments
- Future (2004-05)
  - Install superconducting CKM and 3rdHar cavities
    - CKM deflecting mode cavity systems test and diagnostic for measurement of slice emittance
    - 3rdHar cavity linearizes 1.3 GHz rf for long (low space charge) bunches
    - Note: Work suspended on the latter per specific instruction from DoE.
  - Gun vacuum studies directed toward possibility of polarized beam.
    - Flat beam + polarization could impact LC design
    - LN2 cooled gun (SBIR)



Superconducting RF
CKM Cavity Development

- 3.9GHz deflecting mode cavity for Kaon separated beam line
- Fabrication of full prototypes (9-13 cell)
- Vertical dewar tests of 1& 3 cell
- Next- prototype Horizontal Cryostat
- Chemistry at Argonne





Muon Storage Ring

Goal: Establish the technology base for an affordable, muon-storage-ring-based, neutrino factory.

- Fermilab is one of the three lead-laboratories for the Neutrino Factory and Muon Collider R&D.
- Fermilab is host to the MUCOOL sub-activity, which is the R&D program to develop the technologies required for a muon ionization cooling channel. Primary hardware activities:
  - Study of high-gradient NCRF cavities operating in high-field solenoids (one accelerator PhD to date another active).
  - Development of liquid hydrogen absorbers (led by a consortium of Illinois universities – ICAR).
- The Fermilab group is also instrumental in design & simulation studies focused on significantly reducing the cost of a neutrino factory. (One active PhD student)

MuCool

- Fermilab is the host institution for MuCool.
- 16 Institutions/70 collaborators from US, Europe, and Japan

RF Development
ANL
FNAL
IIT
LBNL
Univ. Mississippi

Beam Diagnostics
ANL
FNAL
IIT
Univ. Chicago

Absorber R&D
FNAL
IIT
KEK
NIU
UIUC
Univ. Mississippi
Univ. Osaka
Univ. Oxford

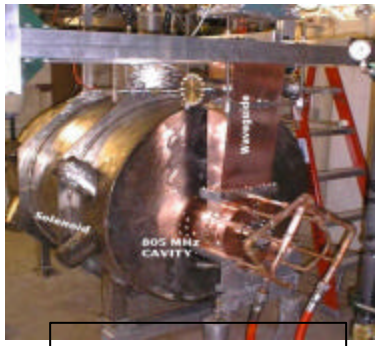
Solenoids
LBNL

Cooling Experiment
ANL
BNL
FNAL
IIT
LBNL
Princeton
UCLA
UIUC
Univ. Mississippi
UC Riverside

Some MUCOOL Accomplishments local to Fermilab & ICAR

Dark current ring measurements on glass plate – ANL/FNAL/IIT

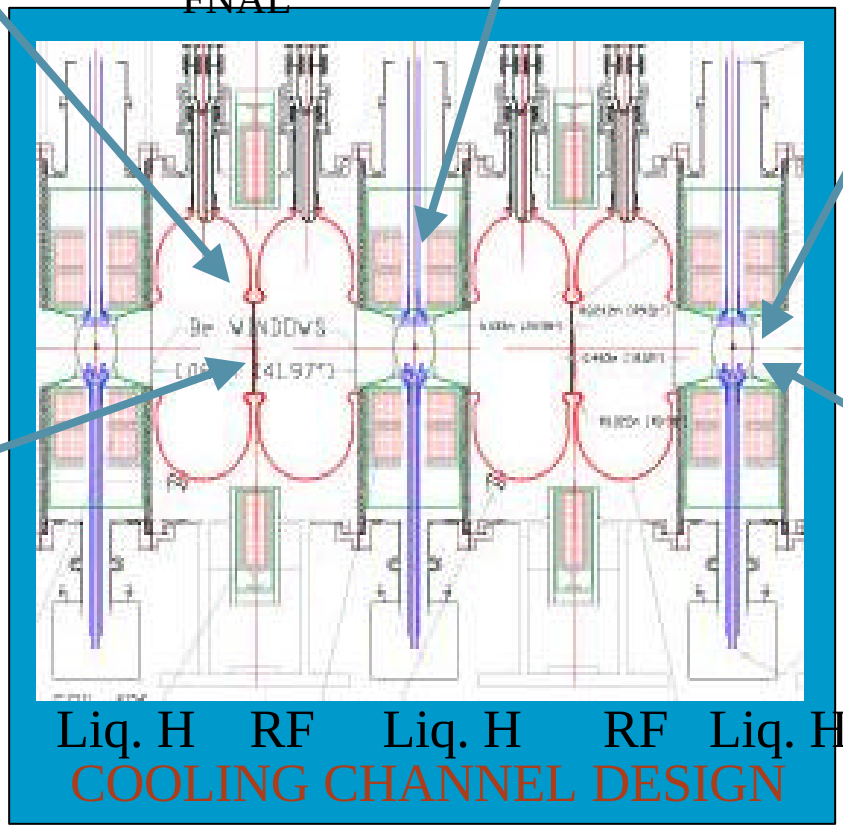
High-Gradient RF Tests in High Magnetic Field - FNAL

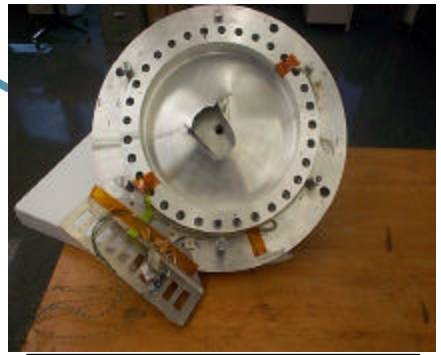


Lab G 805 MHz Test Setup

Bolometer detectors for Window Beam profile – cryogenic setup– U. Chicago

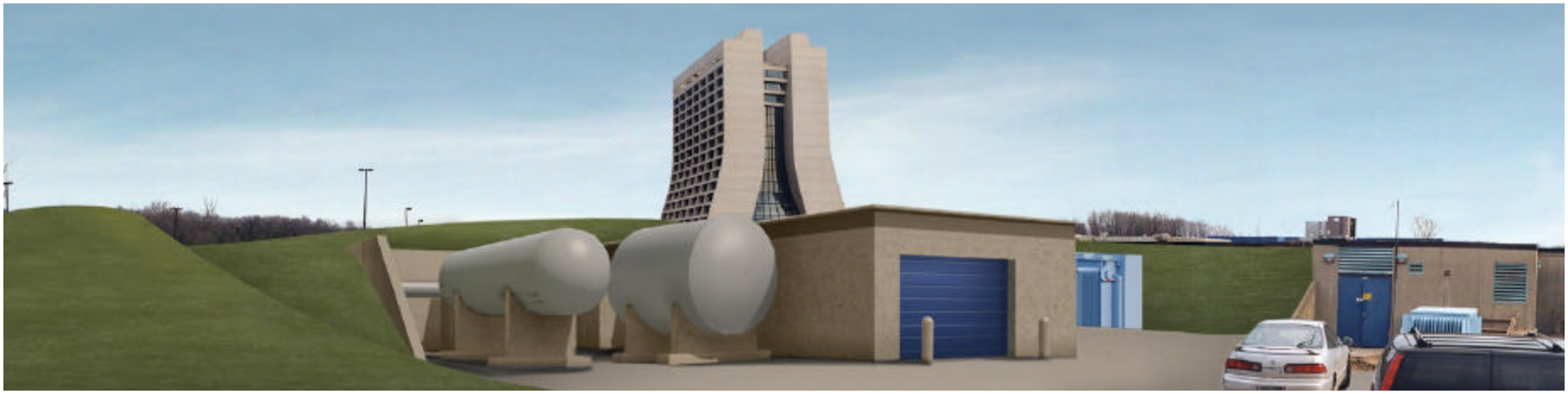
High pressure seal test for high-pressure RF studies – Muons Inc





Window burst tests – ICAR Universities

MuCool Test Facility



MUCOOL Test Facility at end of Fermilab 400 MeV Linac

- Fill Liq. H absorbers: U.S. & Japanese prototypes
- High-Power tests of 201 MHz & 805 MHz Cavities
- Full engineering test of Absorber – Cavity –Solenoid system
- Development of new beam diagnostics
- Eventual engineering test in high-intensity Linac beam

Longer term: Build cooling components for the international (US-Europe-Japan) Cooling experiment (MICE) at the Rutherford Lab.

Muon Storage Ring
Future Plans

FY04

- Equip MUCOOL Test Area
- Continue 805 MHz studies at Lab G
- Fill first absorber with Liq. H2
- Continue preparation for Feasibility Study III

FY05

- 201 MHz High Power Tests
- Fill absorber next to operating cavity
- Prepare 400 MeV beam capability
- Initiate Feasibility Study III

FY06 and Beyond

- Complete Feasibility Study III
- Cooling component engineering tests with Linac beam
- Production of components for the MICE experiment

Superconducting Magnet R&D

Goals:

- Support for ongoing Tevatron collider operations.
- Development of high field superconducting accelerator magnets that could form the basis for a next generation hadron collider (LHC upgrade or VLHC).
  - The low-field superconducting magnet program a Fermilab is effectively over. Some modest (low priority) activities are aimed at documenting achievements.

Superconducting Magnet R&D
High Field Magnet Program

- Long-term goal is development of next generation superconducting magnets with the nominal field **above 10 T**, operating temperature of **4.5 K,** and **field quality/operating margin** appropriate for accelerator applications.

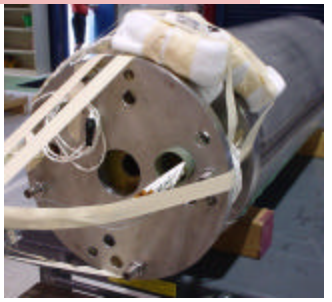
  Þ **Requirements exceed the capabilities of NbTi.**

- The R&D program is concentrated on:
  - **Development of 11-12 T accelerator magnets based on Nb_3Sn**
    - Commercially available but difficult because of brittleness
  - Two designs:
    - traditional shell-type coils with a cosθ current distribution
    - flat block-type coils arranged in the common-coil configuration
  - Two approaches
    - Wind-and-react
    - React-and-wind

High Field Magnet Program

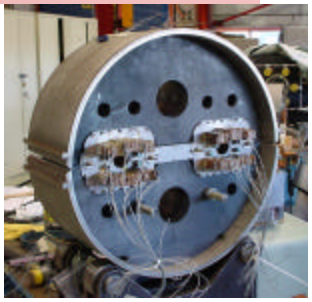
Cosq wind-&-react status

- A series of 1 m long single-bore models of cosθ Nb_3Sn dipole magnets based on wind-and-react technique is being fabricated and tested.
  - design field of 12 T of accelerator quality at 4.5 K in a 43.5-mm bore
  - 4 models fabricated and 3 tested in FY2001-2002
    - Achieved field quality
    - Achieved 6.5 T (60% of short sample)
  - Currently studying quench performance using half-coils and magnetic mirror
    - 1st mirror magnet HFDA03M tested in January, 2003
    - two new tests in March-April, 2003
  - Next short model HFDA05 is planned to be fabricated and tested in September, 2003



High Field Magnet Program
Common Coil Status

- Fabrication and tests of 1-m long common coil dipole models, based on a single-layer, pre-reacted coil.
  - design field of 11 T of accelerator quality at 4.5 K in a 40 mm bore
  - mechanical and technological models have been fabricated and studied in FY2002
  - 1st common coil short model is being fabricated and will be tested in May, 2003
- Experimental studies and optimization of react-and-wind techniques using sub-sized cable.
  - Two 1 meter react&wind Nb_3Sn racetracks fabricated and tested in FY2001-2002.
  - 2nd racetrack tested in FY 2002 reached 78% of its short sample limit (world record for this approach)
  - 3rd racetrack to be tested in April, 2003



Superconducting Magnet R&D
Future Plans

- Produce/test 2-3 different model magnets per year. Goals:
  - Understand and improve magnet quench performance (FY2003-2004)
  - optimize field quality (FY2005-2006)
- Once basic problems are understood we plan to increase the production and tests of HFM models of different types to ~6 per year.
- Develop infrastructure and move to fabrication of long models starting in FY2005-2006 in collaboration with other national laboratories, universities and industry.
- Integration with the LARP effort.
- Superconductor development within the national program

Resources and Budgets

We believe the accelerator R&D program at Fermilab needs to expand significantly, particularly in the linear collider area. Despite our best efforts and intentions we have failed to do this because of intense competition for resources within the laboratory.

Funding Levels (Dollar amounts in millions, Direct costs only)

	FY00	FY01	FY02	FY03	FY04	FY05
Linear Collider/NLC (a)	$1.2	$2.5	$2.5	$2.4	$2.5	$5.0
SCRF (FNPL, CKM, TESLA)	$0.7	$0.8	$2.3	$2.6	$2.0	$4.3
SC Magnet (b)	$3.0	$3.1	$3.6	$3.2	$3.9	$4.4
Muons(c)	$3.1	$1.7	$0.5	$1.1	$1.1	$2.4
TOTAL	$8.0	$8.1	$8.9	$9.3	$9.5	$16.1

(a) Redistribution between x-band and SCRF will occur in FY05 assuming a LC technology decision comes in FY04.
(b) Includes initial buildup of LHC Accelerator Research Program at $0.1, 0.3, 0.4, 0.9M over FY02-05
(c) Includes Muon Collaboration funding and Proton Driver.

Summary

The future accelerator R&D program at Fermilab is striving to develop the technologies that will provide a future for Fermilab in accelerator-based elementary particle physics.

- Support is inadequate to maintain viable programs in multiple areas.
  - This has led us to curtail efforts in some areas in order to support higher priority activities. However, one should not equate "higher priority" with "healthy": ***all programs are on the edge of viability!***
- Targeted activities in the near term include:
  - Linear collider technologies (including FNPL), with the **goal of establishing Fermilab as a credible host/construction partner to a second generation linear collider**, and nurturing nascent accelerator R&D programs in the universities.

Summary

- Superconducting magnets, primarily in the area of high field magnet development with the **goal of developing accelerator quality magnets of >10 T** for future applications (including LHC upgrades) .
- Conceptual development of a new proton source, with the **goal of establishing a design for a MW-class facility** that could enable future hadron-based initiatives at Fermilab.
- Contributions to the U.S. based Muon Collaboration with a **goal of exploring and developing the technological basis for a muon storage ring**.
- Development of **superconducting transverse deflection cavities** for the CKM experiment.